THE D.O.T. CHANNEL SIMULATION AND MODEM TEST FACILITY

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Summary The characteristics and capabilities of a channel measurement and simulation facility are described. This facility has been established at the U. S. Department of Transportation, Transportation Systems Center. The system employs a RAKE type channel measurement system and a compatible digital equivalent tapped delay line channel simulator. The equipment has been used for the evaluation of digital communications problems created by the urban environment. It is currently being used to investigate the performance of modems under a variety of propagation conditions.

Introduction The channel measurement and simulation equipment currently in operation at the Transportation Systems Center, Cambridge, Mass. provides a facility which can be used for the development and evaluation of modems which make efficient use of available radio spectrum and which provide reliable communications under adverse propagation conditions. Both these properties are required for operation in the urban environment [1].

The discussion below describes the channel measurement and simulation hardware. Some interesting channel measurements observed in Boston, Mass. and Chicago are also presented. Finally, the utility of the channel simulator for modem test and evaluation is briefly demonstrated.

Equipment Description The channel playback facility includes two major subsystems: a channel measurement and recording system and a simulator system. Fig. 1. shows the simulator portion of the system. The channel measurement equipment collects channel propagation data in the field. This data is recorded in a manner which is compatible with the channel simulator data input requirement. The recorded data is later used to control

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[1] L. A. Frasco and H. D. Goldfein, “Measurement and Analysis of Urban Radio Channels for Communication System Design”, ITC Proceedings, Vol.VII, pp. 166-171, 1971.

simulator parameters. Thus, the simulator reproduces actual channel propagation characteristics in the laboratory.

Channel Measurement Subsystem Channel propagation characteristics are measured by a RAKE type channel prober. Specifically a channel probing signal is radiated from a typical urban transmitter site. A receiver, multipath data analyzer, and recorder are installed in a mobile van. The interior of the van is shown in Fig. 2.

The transmitted signal is a pseudo-random phase shift keyed carrier. The bit rate of the pseudo-random sequence is 200 kb/s. Thus, the multipath time delay resolution achieved by the channel measurement system is on the order of 5μsec. Clearly, this capability is insufficient to resolve the physical paths which are present at any given time. However, the goal of the channel measurement equipment is to collect data for the simulator facility rather than to investigate the detailed physical properties of the channel. The channel simulator is designed to provide valid reproduction of propagation effects on signals whose bandwidths are 50 kHz or less. For this purpose, a channel prober bit rate of 200 kHz is ample, i.e. the probing signal spectrum is almost flat in the bandwidth of interest.

The received prober signal energy at the mobile van is analyzed by a bank of 10 correlation demodulators. Each demodulator is provided with a locally generated pseudo-random code reference. The relative delays of the 10 code references are staggered at 5μs intervals. Thus, the outputs of each of the correlation demodulators are associated with specific 5 μsec path delay intervals. The absolute delay of the reference sequences is controlled by frequency standards at the transmitter site and in the mobile van.

The analyzer outputs are the real and imaginary components of the complex, time varying impulse response of the channel. These are filtered at baseband in low pass filters with 120 Hz bandwidths. These bandwidths are selected to be wide enough to pass the highest expected doppler rates. The highest carrier frequencies of interest for this application are on the order of 900 MHz. At such carrier frequencies a doppler rate of 120 Hz is produced if the mobile van speed exceeds 90 mph.

The baseband samples of the complex, time varying impulse response are multiplexed and recorded on an instrumentation tape recorder which is installed in the mobile van. The van is also equipped with a special purpose processor which smoothes the samples of the complex, time varying impulse response and displays the channel’s delay power spectrum in realtime. This display is in the form of a bar graph in which the height of each of 10 bars is proportional to the average power observed in each of ten 5μs delay intervals being monitored by correlation demodulators. Fig. 3 illustrates the scope display. The dynamic range of the display (vertical axis) is roughly 28 dB. The scale of the delay (horizontal) axis is 5μsec.

Table 1 summarizes the capabilities of the channel measurement equipment. As presently configured, the system will operate with carrier frequencies at 150 MHz, 450 MHz, or 900 MHz. Of course, other carrier frequencies can be readily implemented. Similarly, the equipment is readily modifiable to provide other code bit rates and sequence lengths.

TABLE 1
Channel Measurement Capabilities

R. F. Carrier Frequency	150 MHz, 450 MHz, or 900 MHz
Modulation	Phase Shift Keyed
Deviation	± 80°
Prober Format	Pseudo Random Sequence
Bit Rate	200 kb/s
Code Length	511 bits
System Range	20 miles (typical, depends on ant. height)
Multipath Delay Resolution	5µsec
Max. Delay Spread Capability	50µsec
Max. Doppler Spread Capability	120 Hz (single-sided)
Analyzer Dynamic Range	40 dB.
Max. Channel Recording Time	1.42 hours/tape reel
Display Dynamic Range	28dB.
Display Averaging Times	1/4, 1, 4, 16, or, 64 sec.

Channel Simulator Subsystem The channel simulator equipment reproduces the effect of channel propagation effects by implementing a tapped delay line channel model. The tapped delay line and its associated tap gain controller are realized at baseband using digital techniques. A total delay of 50µsec is employed with 10 taps, spaced 5µsec apart. The complex impulse response data recorded by the channel measurement equipment can thus be used directly to control the tap gains, in the simulator.

The signal input to the simulator can be at 150 MHz, 50 MHz, or, 900 MHz center frequency. The signal should be constant envelope for optimum performance of the simulator and the bandwidth must be 50 kHz or less. An L. 0. reference at 190 MHz, 490 MHz, or 430 MHz, must also be provided to the simulator for operation at 150 MHz, 450 MHz and 900 MHz, respectively.

The dynamic range of the simulator with only one tap excited is in excess of 40 dB. The unit will not saturate with 9 of the 10 taps fully modulated. So, the total dynamic range of the device is on the order of 58 dB.

The simulator includes provisions for the addition of impulsive noise to the multipath distorted output signal. This subsystem can generate wide band impulsive noise with dynamic range in excess of 60 dB when driven from suitably recorded impulse noise data.

Table 2 summarizes the performance capabilities of the simulator system.

TABLE 2
Simulator Performance

R.F. Center Freq.	.50 MHz, 450 MHz, or, 900 MHz
R.F. Bandwidth (constant envelope)	50 kHz
Max. Delay Spread Cap.	50 µsec
Tap Spacing	5 µsec
Max. Doppler Spread Cap.	120 Hz (single sided)
Worst Case Dynamic Range	40 dB
Total Dynamic Range	58 dB
Impulse Noise Dynamic Range	60 dB
Impulse Noise Bandwidth	1 MHz

Preliminary Experimentation The system has been set-up to take channel data in Boston, Mass. at 150 MHz; and in Chicago, Ill. at 450 MHz.

Fig. 3 shows some interesting multipath features observed in Boston. In particular, Fig. 3 shows the real-time display of the delay power spectrum of the channel with the transmitter mounted on the roof of the D.O.T. Transportation Systems Center, in Cambridge and the mobile van located on Commonwealth Ave., Boston.

A 64 second average is used to obtain the result shown in Fig. 3c. Note that significant multipath energy roughly 10 dB down is received at a delay of more than 15 µsec from the earliest arriving signals.

Fig. 3b and 3a show the differences in delay power spectrum achieved by moving the mobile van 1 ft. along Commonwealth Ave.

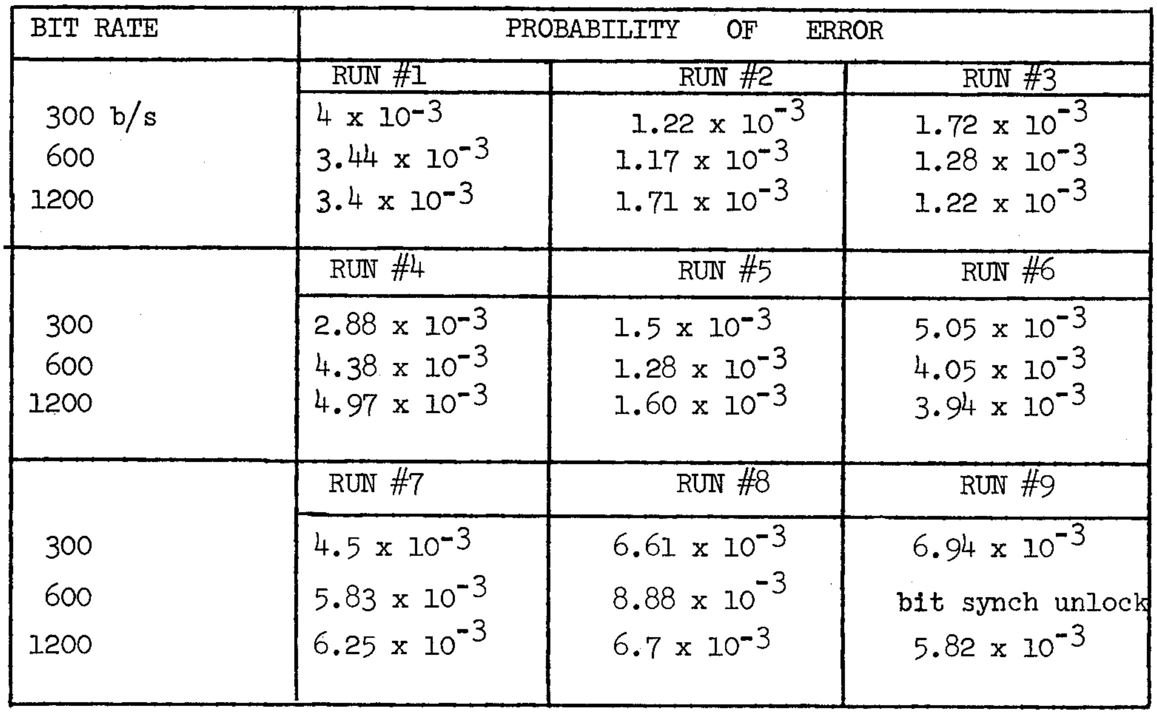
Similar results were observed and recorded in Chicago at 450 MHz. In fact delay spreads in excess of 20µsec were observed when signals were transmitted through the “Loop” area. For most geometries the delay spread is typically on the order of 10 µsec.

Modem Testing with the Channel Simulator Facility In order to demonstrate the utility of the channel simulator for modem design and testing, the performance of a simple FSK modem was measured in the laboratory under a variety of channel conditions. The channel data used was collective in Chicago at 450 MHz.

Nine one minute channel data intervals were selected for the modem. The first 3 minutes are representative of suburban channels. The next 3 minutes are representative of typical urban channels. The last 3 minutes are representative of urban channels with very large delay spreads i.e. between 20 µsec and 25 µsec.

Three modem tests were carried out for each 1 minute channel data interval. Specifically, the probability of bit error was measured for three bit rates, 300 b/s, 600 b/s, and 1200 b/s. The results achieved are summarized in Table 3.

TABLE 3
Modem Test Results



BIT RATE	PROBABILITY OF ERROR		
	RUN #1	RUN #2	RUN #3
300 b/s	4×10^{-3}	1.22×10^{-3}	1.72×10^{-3}
600	3.44×10^{-3}	1.17×10^{-3}	1.28×10^{-3}
1200	3.4×10^{-3}	1.71×10^{-3}	1.22×10^{-3}
	RUN #4	RUN #5	RUN #6
300	2.88×10^{-3}	1.5×10^{-3}	5.05×10^{-3}
600	4.38×10^{-3}	1.28×10^{-3}	4.05×10^{-3}
1200	4.97×10^{-3}	1.60×10^{-3}	3.94×10^{-3}
	RUN #7	RUN #8	RUN #9
300	4.5×10^{-3}	6.61×10^{-3}	6.94×10^{-3}
600	5.83×10^{-3}	8.88×10^{-3}	bit synch unlock
1200	6.25×10^{-3}	6.7×10^{-3}	5.82×10^{-3}

The results tabulated above demonstrate the capabilities of simulator to reproduce the channel effects on modem performance in a controlled and repeatable manner. These capabilities allow the designer to investigate the behavior of modems under adverse conditions induced by multipath fading. For example, the results of Table 3 show that the modem under test has a tendency to lose bit synch when the delay spread is larger than 20 µsec.

Conclusions A channel simulation facility has been established at the U. S. Department of Transportation, Transportation Systems Center. The system is currently being used for the design, test, and evaluation of data modems for transportation systems.

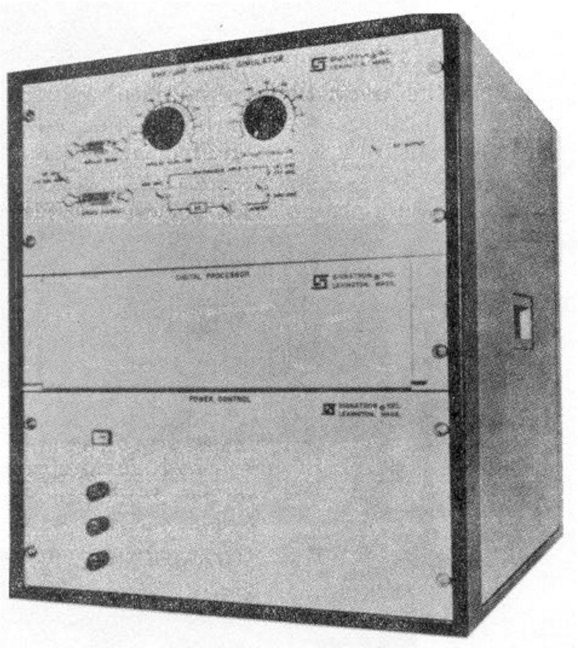


Fig. 1 Channel Simulator

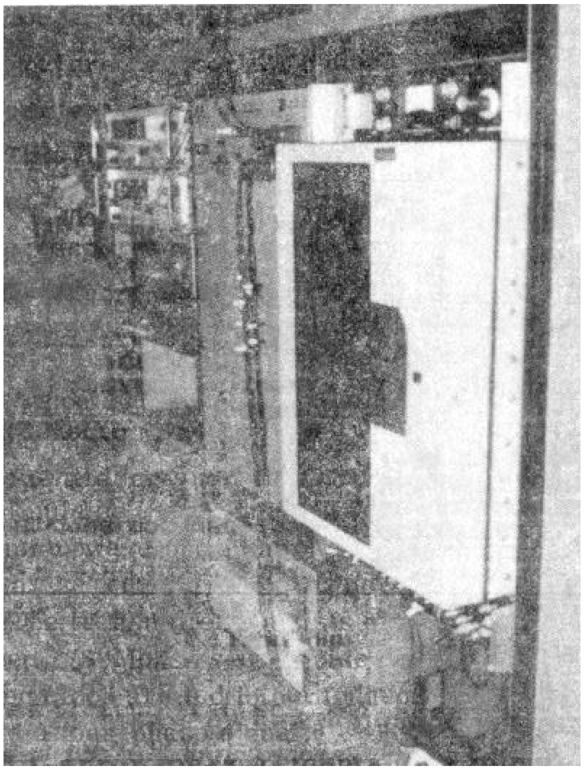
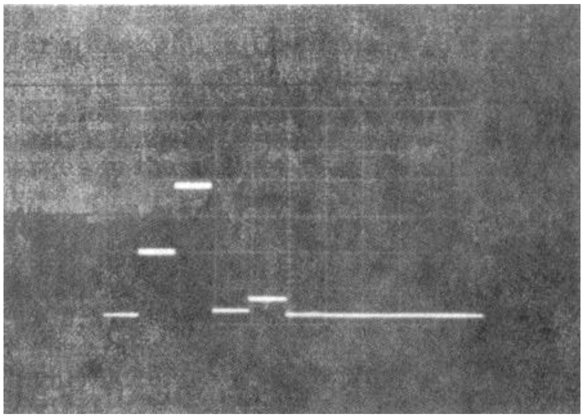
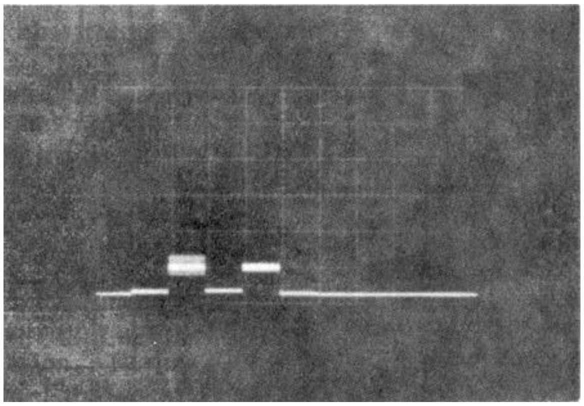


Fig. 2 Interior of Mobile Van

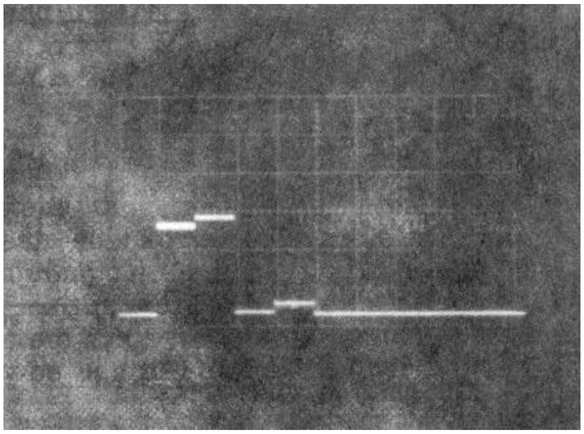
Fig. 3 Real-Time Delay Power Spectrum Display



(a) Delay Power Spectrum (Commonwealth Ave., Boston



(b) Delay Power Spectrum at Location Displaced 1 ft. from (a).



(c) Long-Term Average of (a) and (b)